Characteristics of LED, Photodiode and LDR

Project report

Submitted by

Ameena Safar K

(AB23PHY021)

Under the guidance of

Dr. Santhi A

Associate Professor,

Department of Physics and Centre for Research

St.Teresa's college (Autonomous) Ernakulam.

In partial fulfilment of the requirement of award of

Bachelor Degree of science in Physics.

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ERNAKULAM

CERTIFICATE

This is to certify that the project report entitled "V–I Characteristics of LED, Photodiode and LDR" is a bonafide record of the project work done by Ameena Safar K, submitted to the Department of Physics, St. Teresa's College (Autonomous), Ernakulam, in partial fulfillment of the requirements for the award of the Degree of Bachelor of Science in Physics during the academic year 2025–2026.

The work has been carried out under my supervision and guidance.

Guide

Dr. SANTHI A

Associate Proffesor

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B.Sc PHYSICS

PROJECT REPORT

NAME : AMEENA SAFAR K

REGISTER NUMBER : AB23PHY021

YEAR OF WORK : 2025–26

This is to certify that this project work entitled, "CHARACTERISTICS OF LED, PHOTODIODE AND LDR" is an authentic work done by AMEENA SAFAR K under the guidance and supervision of Dr. Santhi A, Associate Professor, Department of Physics, St. Teresa's College (Autonomous), Ernakulam.

Submitted for the University examination held at St. Teresa's College, Ernakulam.

Santhi

Staff member in-charge

Dr. SANTHI A

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Dr. MARY VINAYA

Department of Physics ★ St. Teresa's College (Autonomous) ★ Ernakulam

Date:

Examiner:

DECLARATION

I, Ameena Safar K (Reg. No: AB23PHY021), final B.Sc. Physics student, Department of Physics, St. Teresa's College (Autonomous), Ernakulam, do hereby declare that the project work entitled "V–I CHARACTERISTICS OF LED, PHOTODIODE AND LDR" has been originally carried out under the guidance and supervision of Dr. Santhi A, Associate Professor, Department of Physics, St. Teresa's College (Autonomous), Ernakulam, in partial fulfillment for the award of the Degree of Bachelor of Science in Physics.

I further declare that this project has not been partially or wholly submitted for any other purpose and the data included in this project is true to the best of my knowledge.

PLACE: ERNAKULAM

Name: Ameena Safar. K

DATE: 30-03-26

ACKNOWLEDGEMENT

First and foremost, I would like to thank God Almighty for showering His blessings on me in successfully completing this endeavour.

I wish to express my sincere gratitude to Dr. Santhi A, my project guide, Department of Physics, for her valuable guidance, constant encouragement, constructive suggestions, and timely support throughout the course of this project work. Her expert supervision and motivation have been instrumental in the successful completion of this study.

I extend my deep sense of gratitude to Dr. Mary Vinaya, Head of the Department of Physics, for providing the necessary facilities and for her kind support and encouragement.

I also express my heartfelt thanks to all the teaching and non-teaching staff of the Department of Physics for their cooperation and assistance during the completion of this project.

Name: Ameena Safar.K

ABSTRACT

This project deals with the experimental study of the VI characteristics of LED, photodiode, and LDR. These optoelectronic devices play an important role in modern electronic and communication systems. The experiment aims to analyse the current-voltage relationship and understand the working principles of each device under different operating conditions. The obtained graphs confirm the theoretical behaviour of these devices.

CONTENT

INTRODUCTION

Optoelectronic devices are widely used in modern technology for sensing, communication, and display applications. Among these, the LED, photodiode, and LDR are important components. The performance of these devices can be understood by studying their VI (Voltage-Current) characteristics. This project focuses on experimentally analysing these characteristics and comparing them with theoretical expectations.

Chapter 1:- LED (Light Emitting Diode)

Introduction

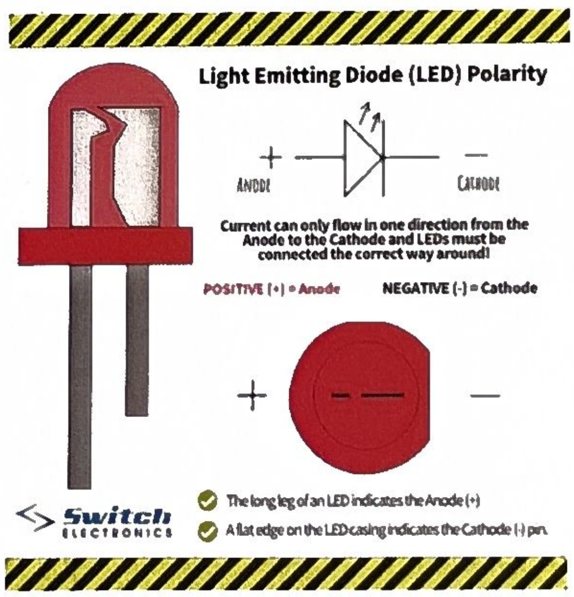
A Light Emitting Diode (LED) is a special type of p–n junction semiconductor diode that emits light when it is forward biased. Unlike ordinary diodes which convert electrical energy mainly into heat, LEDs convert electrical energy directly into light energy. Due to their high efficiency, low power consumption, compact size, and long operational life, LEDs have become one of the most widely used optoelectronic devices in modern electronics.

Light Emitting Diodes (LEDs) are semiconductor devices that convert electrical energy into light through a process known as injection luminescence.

LEDs are extensively used in display systems, indicator lamps, traffic signals, communication systems, and illumination applications.

fig 1.1

fig 1.2



Principle of Operation: Injection Luminescence

The fundamental mechanism of an LED is a p-n junction diode operated under forward bias.

• Minority Carrier Injection: When forward-biased, majority carriers from both sides of the junction cross the depletion layer. Electrons enter the p-type material and holes enter the n-type material, where they become minority carriers. This increase in local minority carrier population is termed "minority carrier injection".

• Radiative Recombination: These excess minority carriers diffuse away from the junction and recombine with majority carriers. In an ideal LED, every injected electron undergoes radiative recombination, emitting a photon.

• Quantum Efficiency: In practice, not all recombinations produce light. Efficiency is measured by the quantum efficiency, defined as the rate of photon emission divided by the rate of electron supply.

LED Materials and Colour:-

The emission wavelength (λ) is primarily determined by the energy band gap (Eg) of the material,following the relation

$hc\backslash \lambda \sim Eg$

Material	Peak emission (nm)	Typical colour
GaAs	910-1020	Infrared
GaAsP	650	Red
GaP(N-doped)	555	Green
InGaAs/SiC	450-470	Blue

Device Construction and Efficiency Challenges:-

While internal quantum efficiency can be high, external efficiency is often limited by optical losses:

• Total Internal Reflection: High refractive indices of semiconductor materials (like III-V compounds) result in very small critical angles. Light striking the surface at an angle greater than the critical angle is reflected back and trapped within the device.

• Reabsorption: Emitted radiation may be reabsorbed by the semiconductor material before it can escape, particularly in direct bandgap materials.

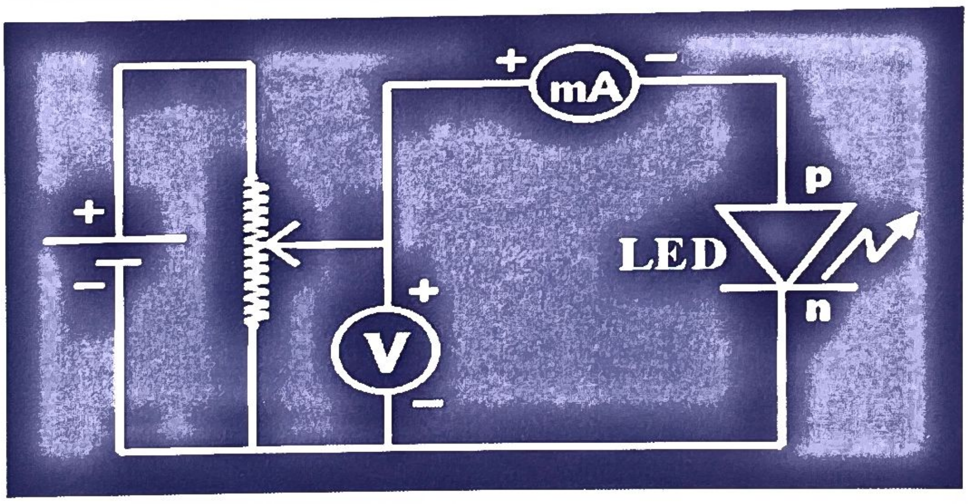
Solutions to Improve Extraction:-

1. Hemispherical Domes: Shaping the semiconductor material into a dome ensures more radiation strikes the interface at an angle less than the critical angle.

2. Plastic Encapsulation: Surrounding the junction with plastic reduces reflection losses at the semiconductor/plastic interface compared to a semiconductor/air interface.

3. Surface Contacts: Using small electrical contacts (e.g.Aluminum) on the upper surface allows more radiation to escape without being blocked or absorbed.

fig 2.1



Thin film layer structure of the semiconductor inside the LED

Modern LEDs are fabricated using thin film deposition techniques such as Metal Organic Chemical Vapor Deposition (MOCVD).

The device consists of multiple semiconductor layers grown one over another on a substrate. Each thin layer has a specific electrical and optical function.

➢ Layer-by-Layer Structure

❖ Substrate Layer

- Common materials: Sapphire (Al_2O_3), Silicon Carbide (SiC), or Silicon (Si).
- Provides mechanical support.
- Helps in heat dissipation.
- Does not directly participate in light emission.

❖ Buffer Layer

- Usually made of GaN or AlN.
- Deposited between substrate and active layers.
- Reduces lattice mismatch and crystal defects.
- Improves overall device efficiency.

❖ n-Type Semiconductor Layer

- Made of n-type Gallium Nitride (GaN).
- Doped with Silicon (Si).
- Contains excess electrons (majority carriers).
- Thickness: Few micrometers.

Function:-

Provides electrons for recombination.

❖ Active Region (Multiple Quantum Wells – MQW)

This is the most important layer of the LED.

- Made of alternating thin layers of InGaN and GaN.
- Thickness: Few nanometers.
- Forms quantum wells that confine charge carriers.

Function:-

- Electrons from n-region and holes from p-region recombine here.
- Energy released as photons.
- Determines color of LED (depends on band gap).

❖ p-Type Semiconductor Layer

- Made of p-type GaN.
- Doped with Magnesium (Mg).
- Contains holes (majority carriers).

Function:-

Provides holes for recombination.

❖ Transparent Conductive Layer

- Usually Indium Tin Oxide (ITO).
- Spreads current uniformly across surface.
- Transparent to allow light extraction.

❖ Metal Contacts

- p-contact (top)
- n-contact (bottom or side)

Function:-

Provides electrical connection to external circuit.

➤ Working of Thin Film LED Structure

When forward bias is applied:

1. Electrons move from n-type layer.
2. Holes move from p-type layer.
3. Both meet in the active region.
4. Electron-hole recombination occurs.
5. Energy is released as light (photons).

The wavelength (color) of emitted light depends on the band gap energy of the active material.

➤ Advantages of Thin Film Structure

- High efficiency
- Better light extraction
- Reduced defects
- Compact design
- Suitable for high brightness LEDs

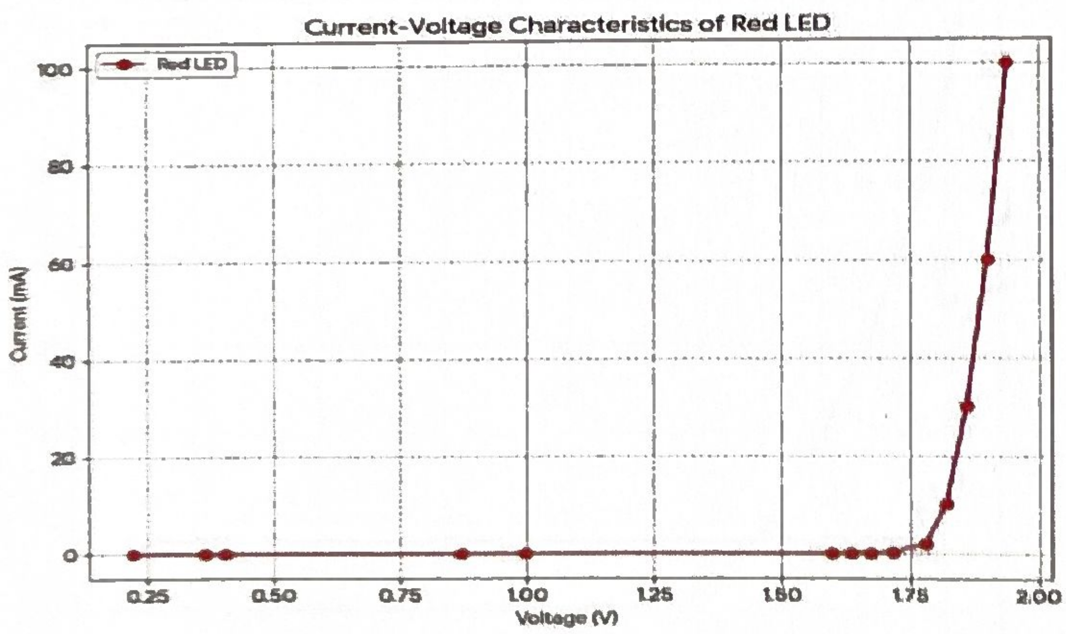
The thin film layered structure of an LED is carefully engineered to maximize electron–hole recombination in the active region. Each semiconductor layer plays a specific role in current injection, recombination, and light extraction. The use of quantum well thin films significantly enhances LED efficiency and brightness.

Red Led

V (v)	I (mA)
0.222	0
0.273	0
0.365	0
0.397	0
0.405	0
0.871	0
0.997	0
1.533	0.01 (glow start)
1.599	0.02
1.635	0.05
1.715	0.25
1.837	0.5
1.911	6
2.13	14 (glow max)

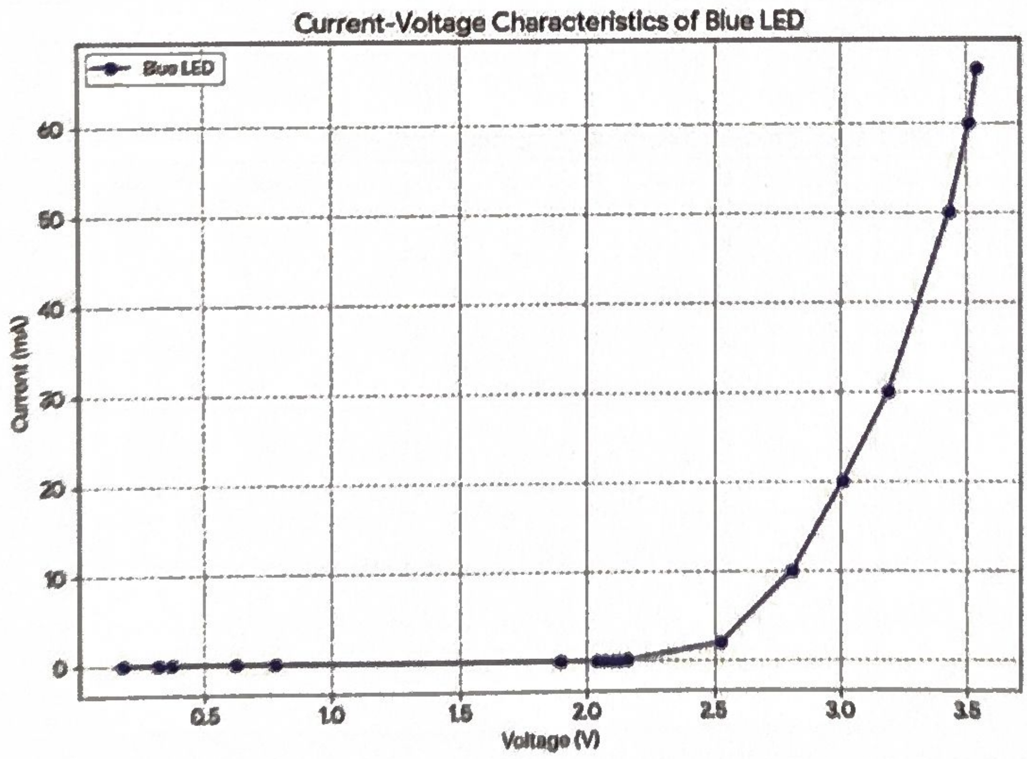
From the graph knee voltage =1.76v

λ =698.3nm



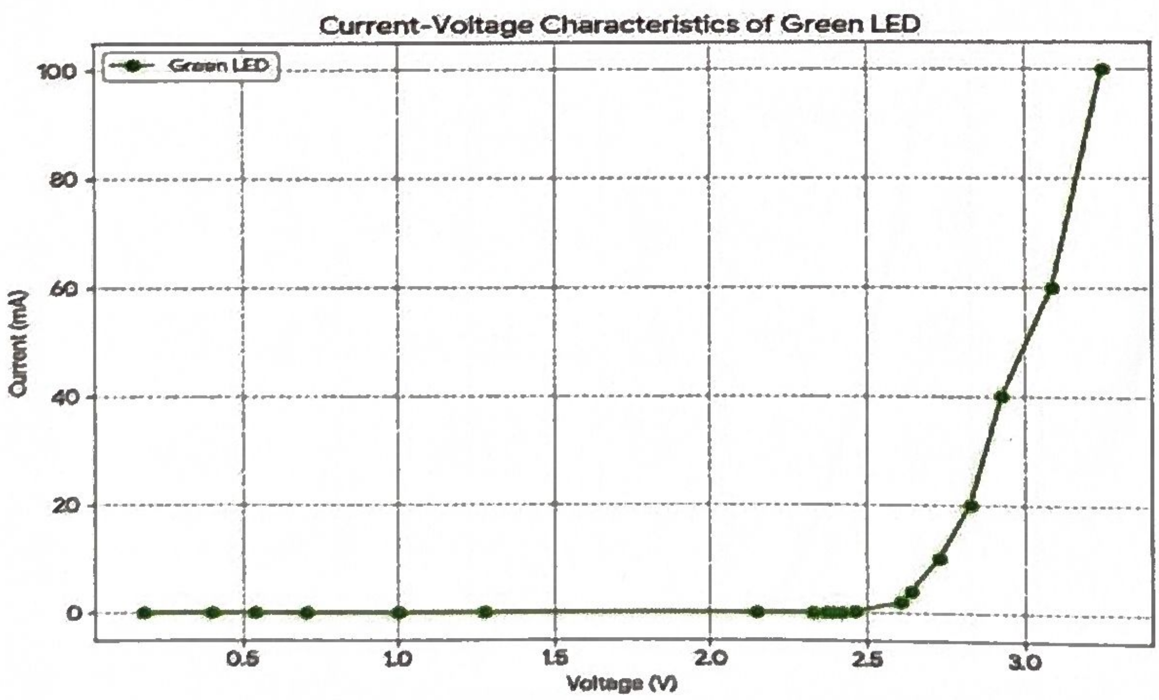
Blue Led

V (v)	I(mA)
0.182	0
0.777	0
1.896 (V turn ON)	0.005 (glow start)
2.04	0.010
2.07	0.015
2.10	0.025
2.13	0.05
2.16	0.10
2.53	2
2.81	10
3.01	20
3.43	50
3.51	60
3.54	66 (glow max)



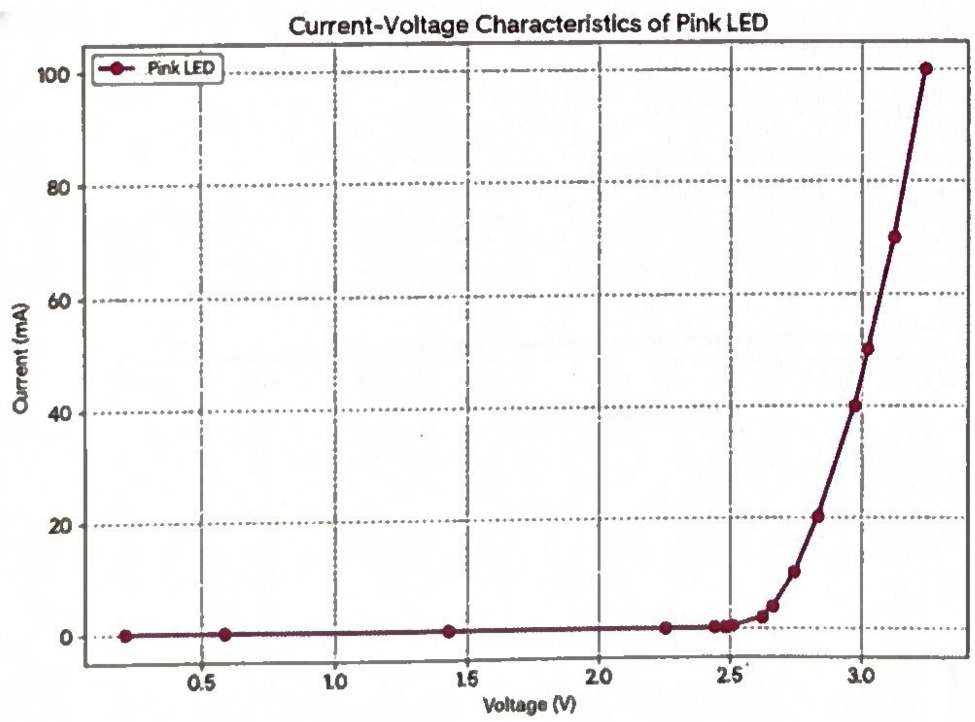
Green Led

V (v)	I(mA)
0.183	0
1.280	0
2.15 (V TURN ON)	0.005 (glow start)
2.33	0.010
2.37	0.025
2.39	0.040
2.42	0.060
2.46	0.210
2.61	2
2.64	4
2.73	10
2.83	20
3.09	60
3.25	100 (glow max)



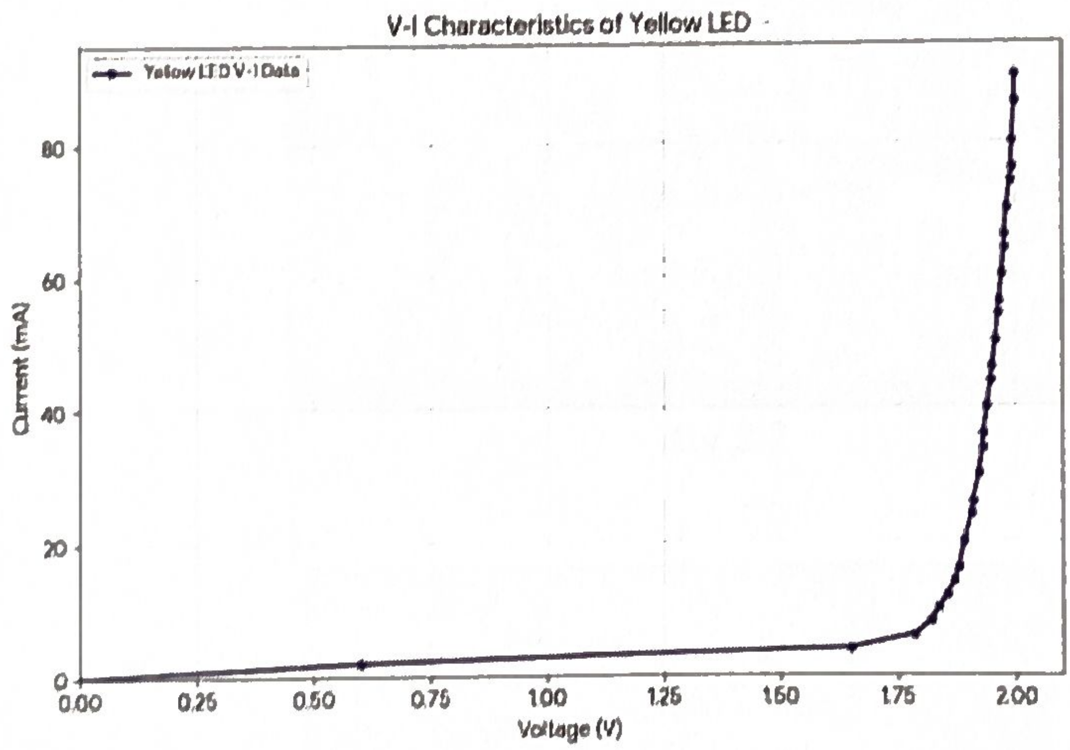
Pink Led

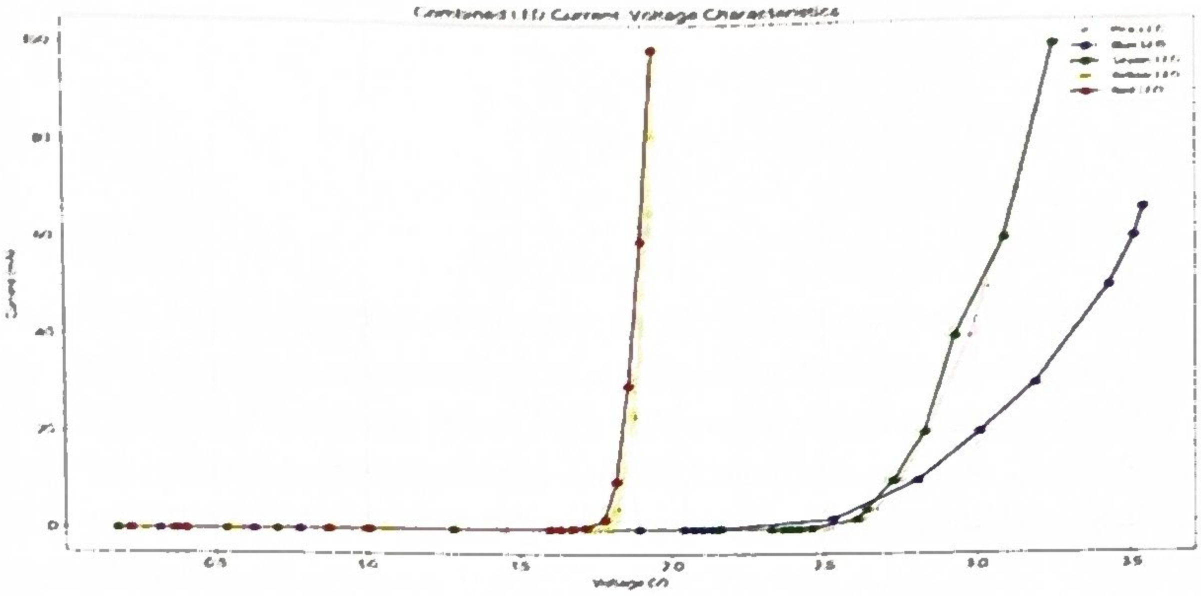
V (v)	I(mA)
0.025	0
0.595	0.020
1.450	0.050
2.26 (V turns ON)	0.110 (glow start)
2.45	0.180
2.49	0.260
2.51	0.350
2.52	0.460
2.63	2
2.67	4
2.75	10
2.84	20
2.98	40
3.03	50
3.13	70
3.25	100 (glow max)



Yellow Led

V (v)	I(mA)
0	0
1.12	0
1.82 (V turn ON)	10
2	20
2.05	30
2.08	40
2.10	50
2.11	60
2.12	70 (glow max)





EXPERIMENTAL SETUP

fig 2.2

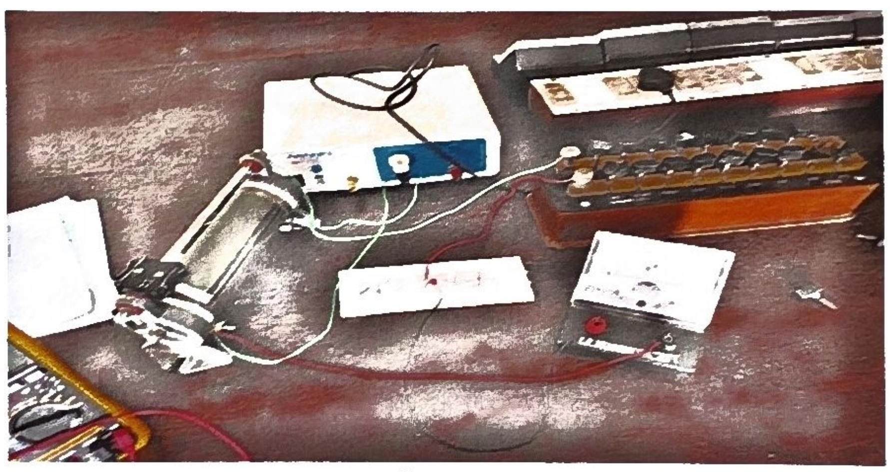
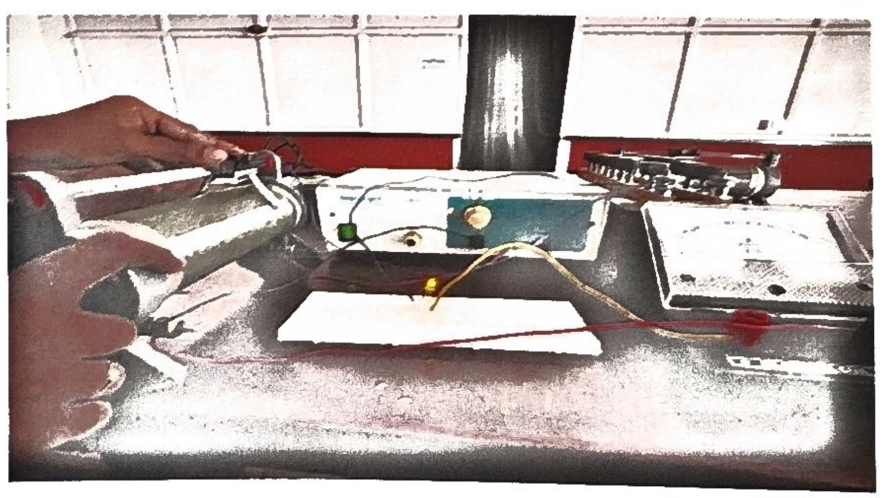


fig 2.3



Chapter 2:-PHOTODIODE

Introduction

A photodiode is a light-sensitive semiconductor device that converts light energy into electrical energy. It is a special type of p–n junction diode designed to operate mainly in reverse bias condition. When light falls on the photodiode, it generates charge carriers which result in an electric current. Due to this property, photodiodes are widely used in optical communication systems, light detection circuits, and sensing applications.

Principle

The working of a photodiode is based on the principle of the photoelectric effect.

When photons of sufficient energy fall on the p–n junction:

- They transfer energy to electrons.
- Electron–hole pairs are generated.
- In reverse bias condition, the electric field across the depletion region separates these charge carriers.
- This movement of charge carriers produces a reverse current known as photocurrent.

The magnitude of photocurrent is directly proportional to the intensity of incident light.

Construction

A photodiode consists of:

- P-type semiconductor layer
- N-type semiconductor layer
- P–N junction
- Transparent window to allow light to enter

- Two metallic contacts (Anode and Cathode)

The junction is usually enclosed in a transparent casing so that light can easily reach the depletion region. The depletion region is made wider to improve sensitivity .

fig 3.1

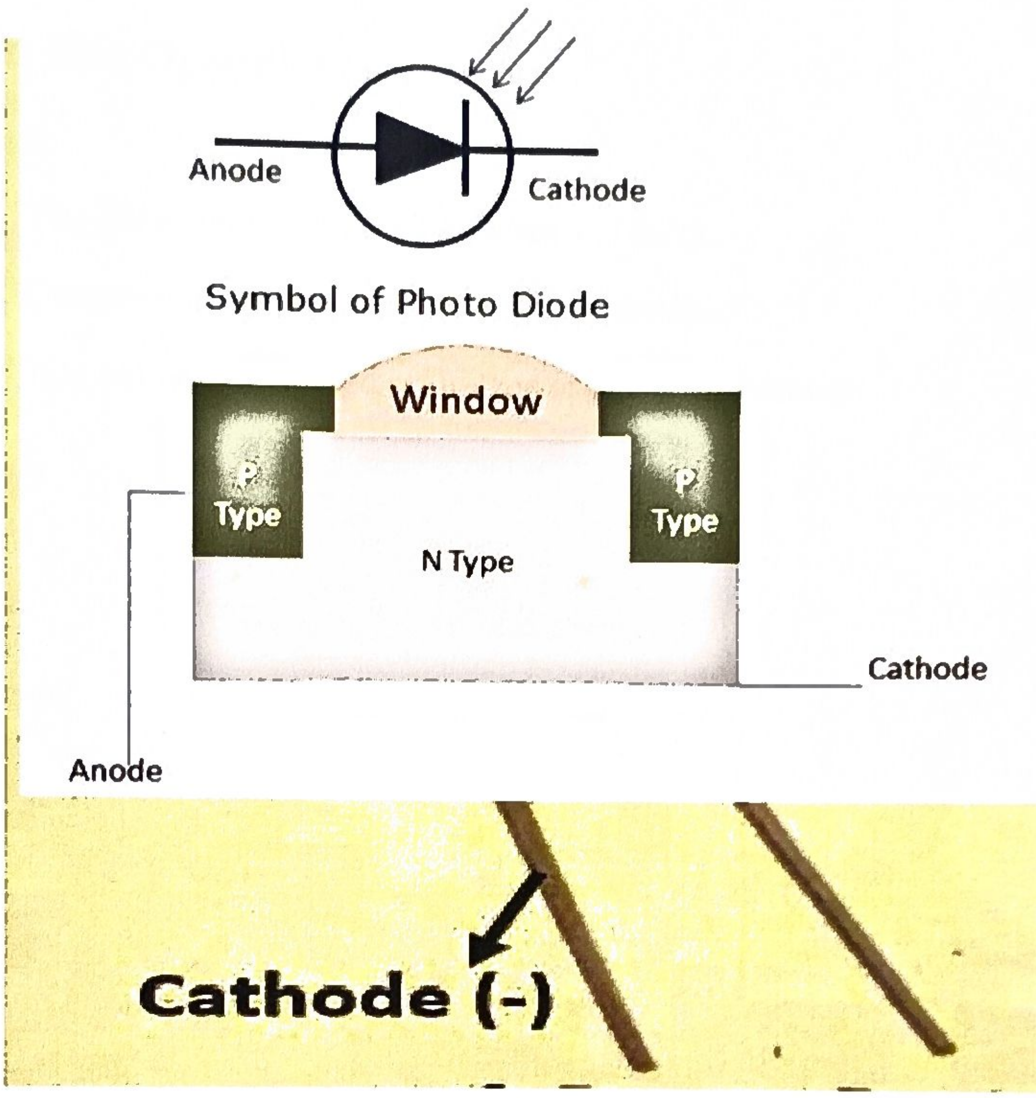


fig 3.2

Working of Photodiode

(a) Reverse Bias Operation:-

Photodiodes are normally operated in reverse bias because:

- It increases the width of depletion region.
- It improves response time.
- It allows better separation of generated charge carriers.

In dark condition:-

- Only a very small reverse current flows.
- This current is called dark current.

Under illumination:-

- Light generates electron–hole pairs.
- Reverse current increases.
- The increase in current is proportional to light intensity.

(b) Forward Bias Operation:-

In forward bias:

- The photodiode behaves like a normal diode.
- Current increases exponentially with voltage.
- It is not normally used in this mode for light detection.

CIRCUIT DIAGRAM

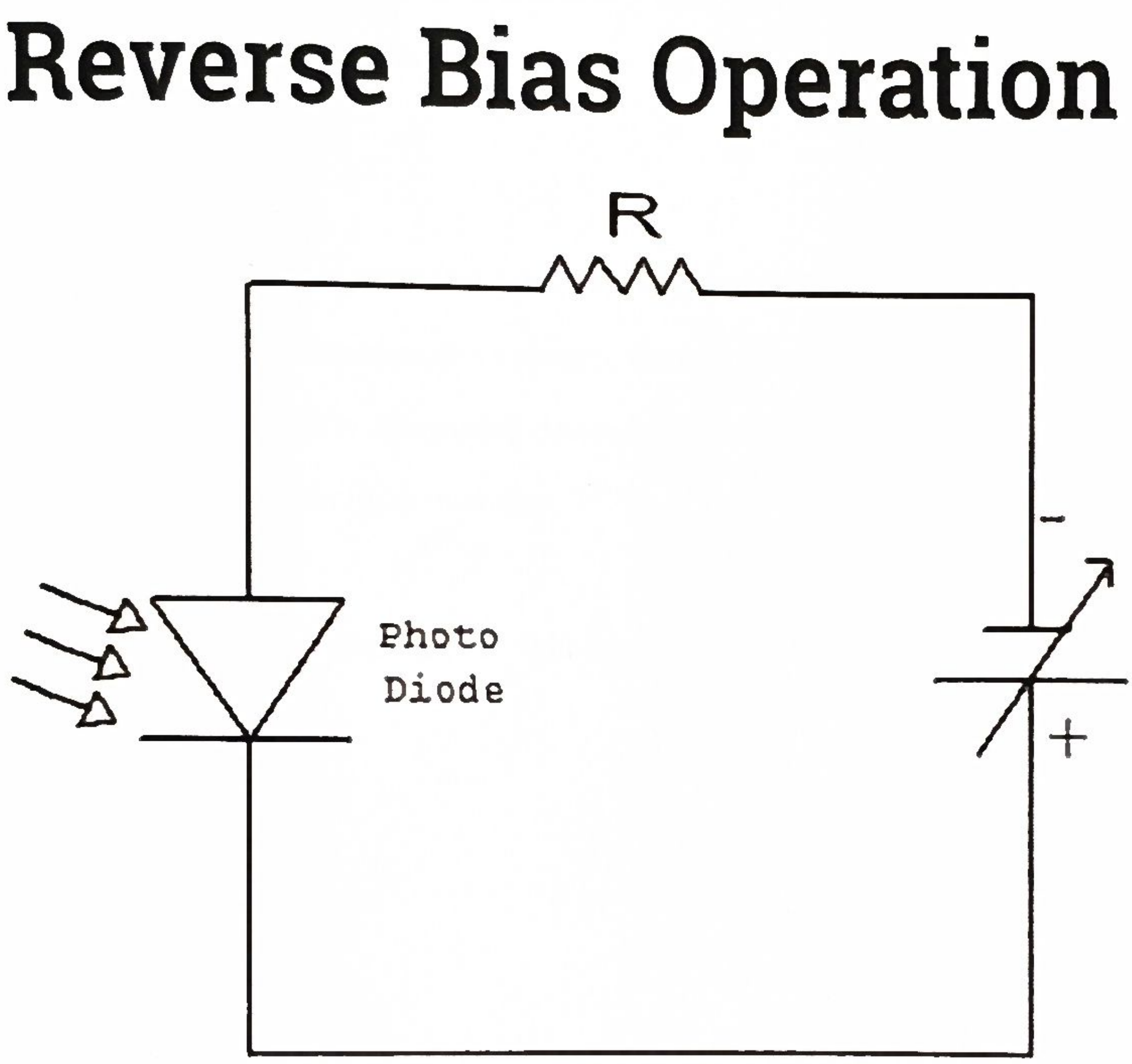


fig 3.3

V–I Characteristics of Photodiode

The V–I characteristics show two important regions:

Forward Bias Region

- Current increases exponentially with applied voltage.
- Similar to ordinary diode behaviour.

Reverse Bias Region

- In dark → small constant reverse current (dark current).
- Under illumination → reverse current increases.
- Curve shifts downward (more negative current) with increase in light intensity.

Thus, the reverse current depends on light intensity rather than voltage.

Advantages :-

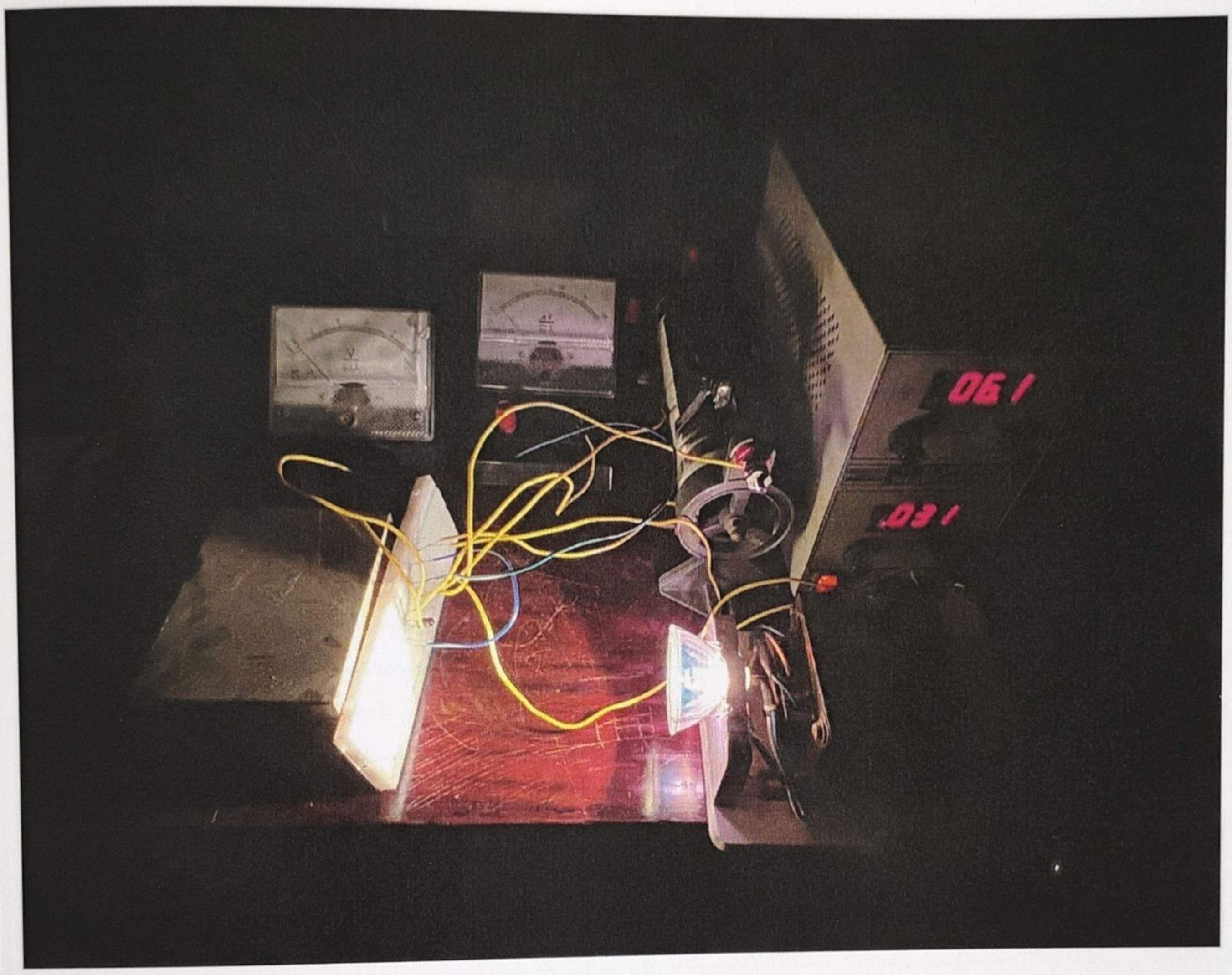
- Fast response at time
- High sensitivity

Applications:-

- Optical fiber communications
- Light sensors
- Smoke detectors
- Automatic switching circuits
- Medical instruments
- Solar energy detection systems

EXPERIMENTAL SETUP

fig 3.4



Observations

At intensity 2

Reverse biased

V (v)	I (mA)
0.20	0
0.4	0
0.8	0
1	0
2	0
6.2	2
7.2	2
8.2	2
9.8	2

Forward biased

V (v)	I (mA)
0.2	0
0.4	0.2
0.6	0.2
0.8	0.2
1	0.2
1.2	0.4
1.8	0.6
2	0.6
2.4	0.6
2.6	0.6
3	0.8
4	1
5	1.2

At intensity 4

Reverse biased

V (v)	I (mA)
0.2	0
0.4	2
2	4
3	6
6.8	8
7	8
7.2	8
7.4	8
7.6	8
7.8	8
8	8
8.6	8
8.8	8

Forward Biased

V (v)	I (mA)
0.4	0
0.6	0.2
0.8	0.4
1.4	0.4
1.8	0.4
2	0.6
2.4	0.6
2.6	0.6
3.2	0.8
3.4	0.8
3.6	1
4.4	1.2
5.6	1.4

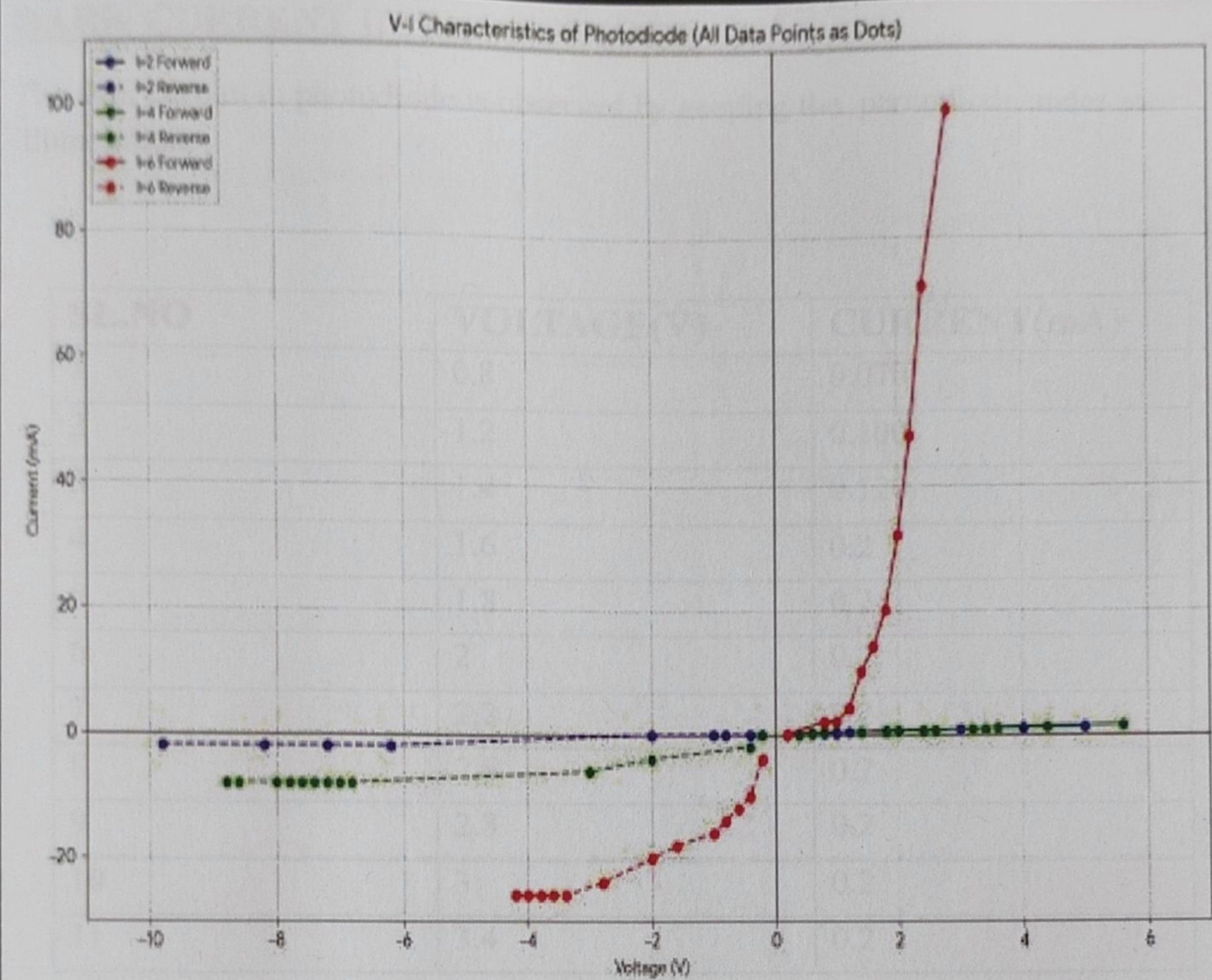
At intensity 6

Reverse biased

V (v)	I (mA)
0.2	4
0.4	10
0.6	12
0.8	14
1	16
1.6	18
2	20
2.8	24
3.4	26
3.6	26
3.8	26
4	26
4.2	26

Forward biased

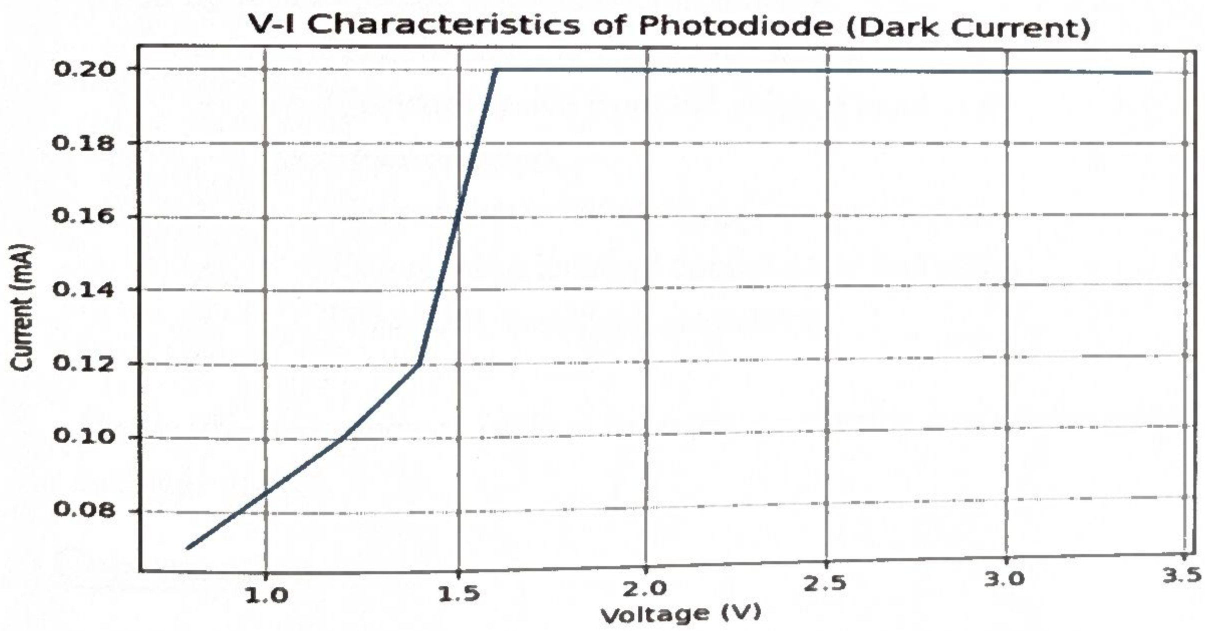
V (v)	I (mA)
0.2	0
0.8	2
1	2
1.2	4
1.4	10
1.6	14
1.8	20
2	32
2.2	48
2.4	72
2.8	100


V-I Characteristics of Photodiode (All Data Points as Dots)
I=2 Forward
I=2 Reverse
I=4 Forward
I=4 Reverse
I=6 Forward
I=6 Reverse
Current (mA)
Voltage (V)
100
80
60
40
20
0
-20
-10
-8
-6
-4
-2
0
2
4
6

DARK CURRENT IN PHOTODIODE

The dark current in photodiode is observed by keeping the photodiode under zero illumination.

SL.NO	VOLTAGE(V)	CURRENT(mA)
1	0.8	0.070
2	1.2	0.100
3	1.4	0.120
4	1.6	0.2
5	1.8	0.2
6	2	0.2
7	2.2	0.2
8	2.6	0.2
9	2.8	0.2
10	3	0.2
11	3.4	0.2



Chapter 3:-LDR(Light dependent Resistor)

Introduction

A Light Dependent Resistor (LDR), also known as a photoresistor, is a passive semiconductor device whose resistance varies according to the intensity of incident light. Unlike photodiodes and LEDs, an LDR does not produce light or current directly; instead, its resistance changes when exposed to light. Due to this property, LDRs are widely used in automatic lighting systems, light sensors, and alarm circuits.

A polarizer is an optical device that converts unpolarized light into plane (linearly) polarized light. In natural light, the vibrations of the electric field occur in all possible directions perpendicular to the direction of propagation. A polarizer allows vibrations only in one particular direction and absorbs or blocks the vibrations in all other directions.

Principle

The working of an LDR is based on the principle of photoconductivity.

When light falls on the semiconductor material:

- Photons transfer energy to electrons.
- Electrons move from the valence band to the conduction band.
- The number of free charge carriers increases.
- As a result, electrical conductivity increases.
- Therefore, resistance decreases.

Hence, the resistance of LDR is inversely proportional to the intensity of incident light.

Construction

An LDR is made of high-resistance semiconductor materials such as:

- Cadmium Sulphide (CdS)
- Cadmium Selenide (CdSe)

The construction includes:

- A thin semiconductor layer arranged in a zigzag pattern.

- Two metallic contacts for electrical connection.
- A transparent protective casing to allow light to enter.

The zigzag pattern increases the effective surface area, making the device more sensitive to light.

Working of LDR

In Dark Condition

- Very few free electrons are available.
- Resistance is very high (in megaohms).
- Current flow is very small.

Under Illumination

- Light generates more free electrons.
- Conductivity increases.
- Resistance decreases significantly.
- Current increases.

Thus, LDR behaves as a variable resistor controlled by light intensity.

Characteristics of LDR

The main characteristic of LDR is the variation of resistance with light intensity.

- In darkness → High resistance
- In bright light → Low resistance

The resistance vs light intensity graph shows a non-linear decreasing curve.

Advantages:-

- Simple construction
- Low cost
- High sensitivity to visible light
- Easy to use in circuit

Applications:-

- Automatic street light control

- Light intensity meters
- Burglar alarm systems
- Camera light meter

fig 4.1

EXPERIMENTAL SETUP

fig 4.2

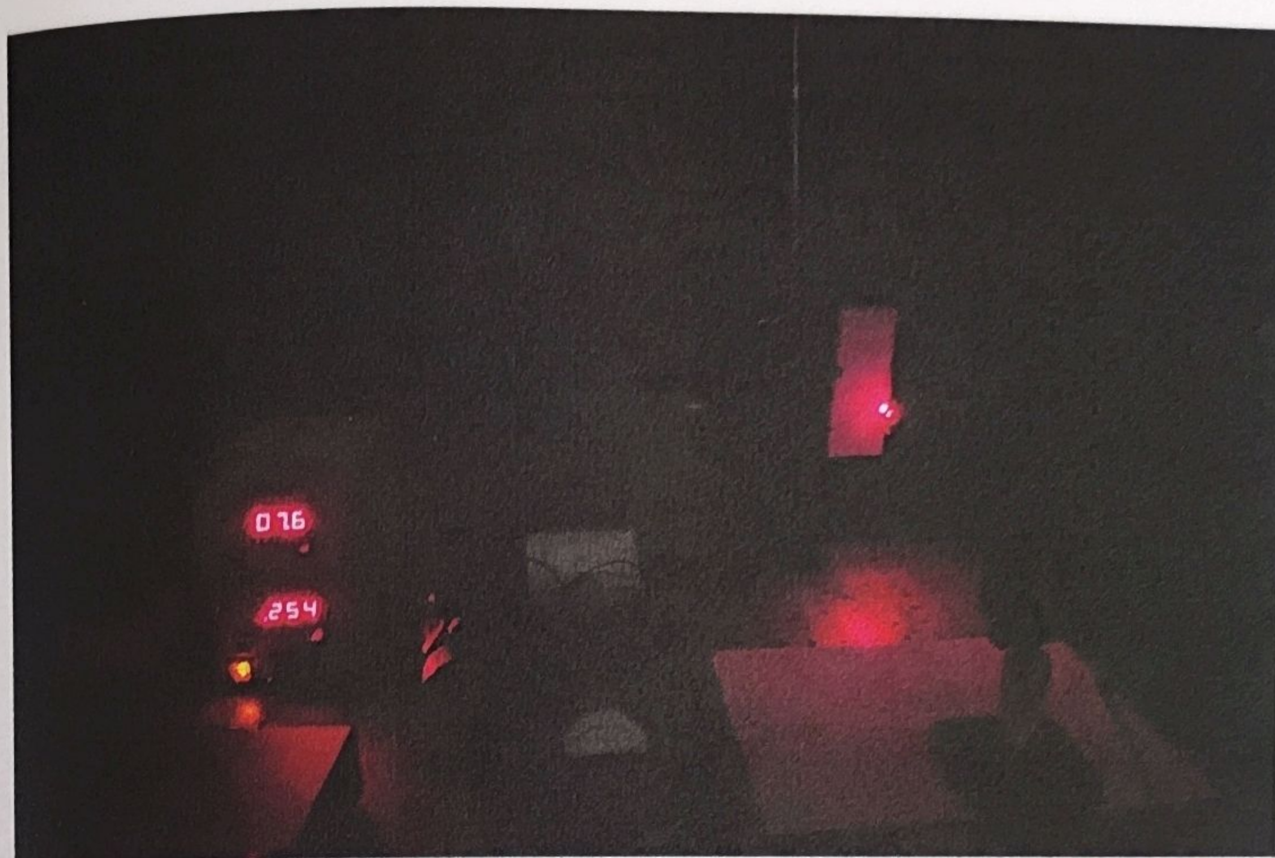
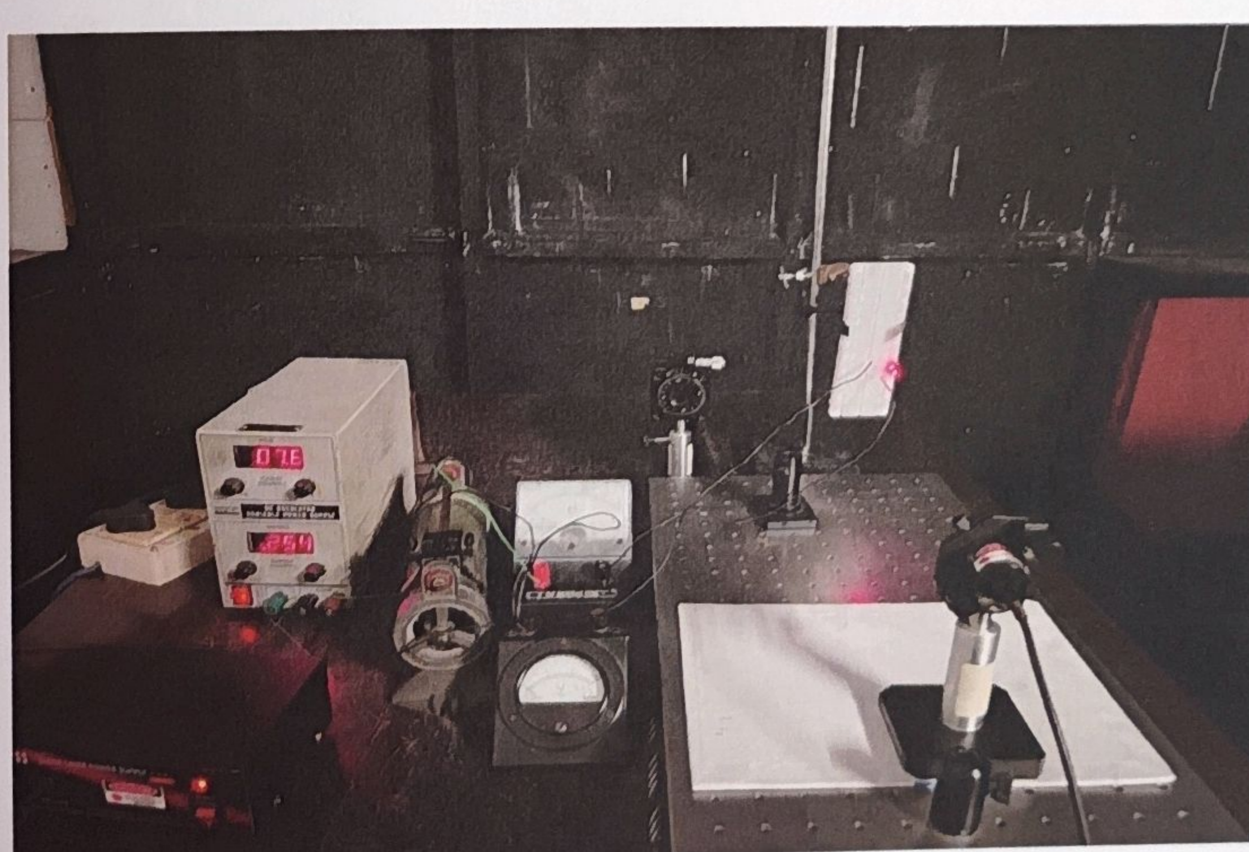


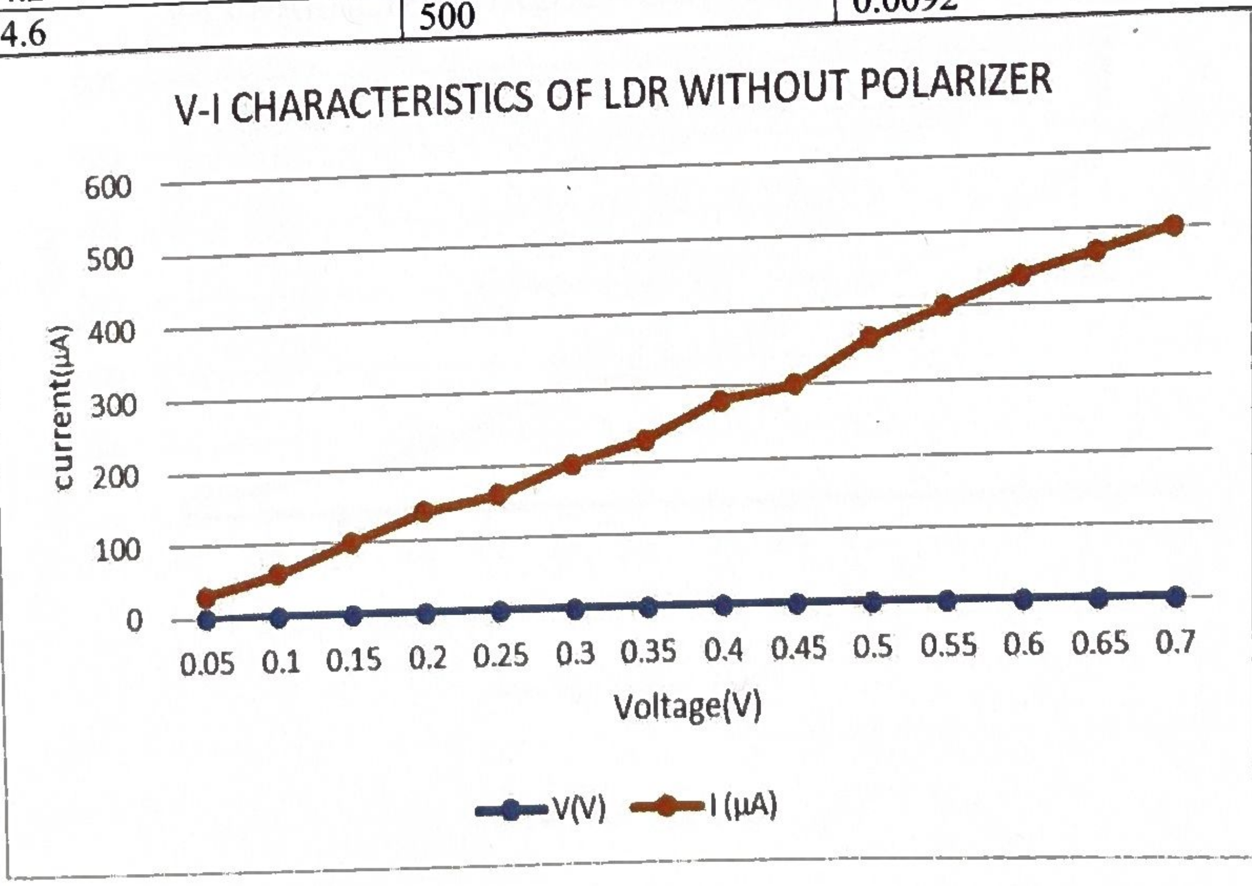
fig 4.3



OBSERVATIONS

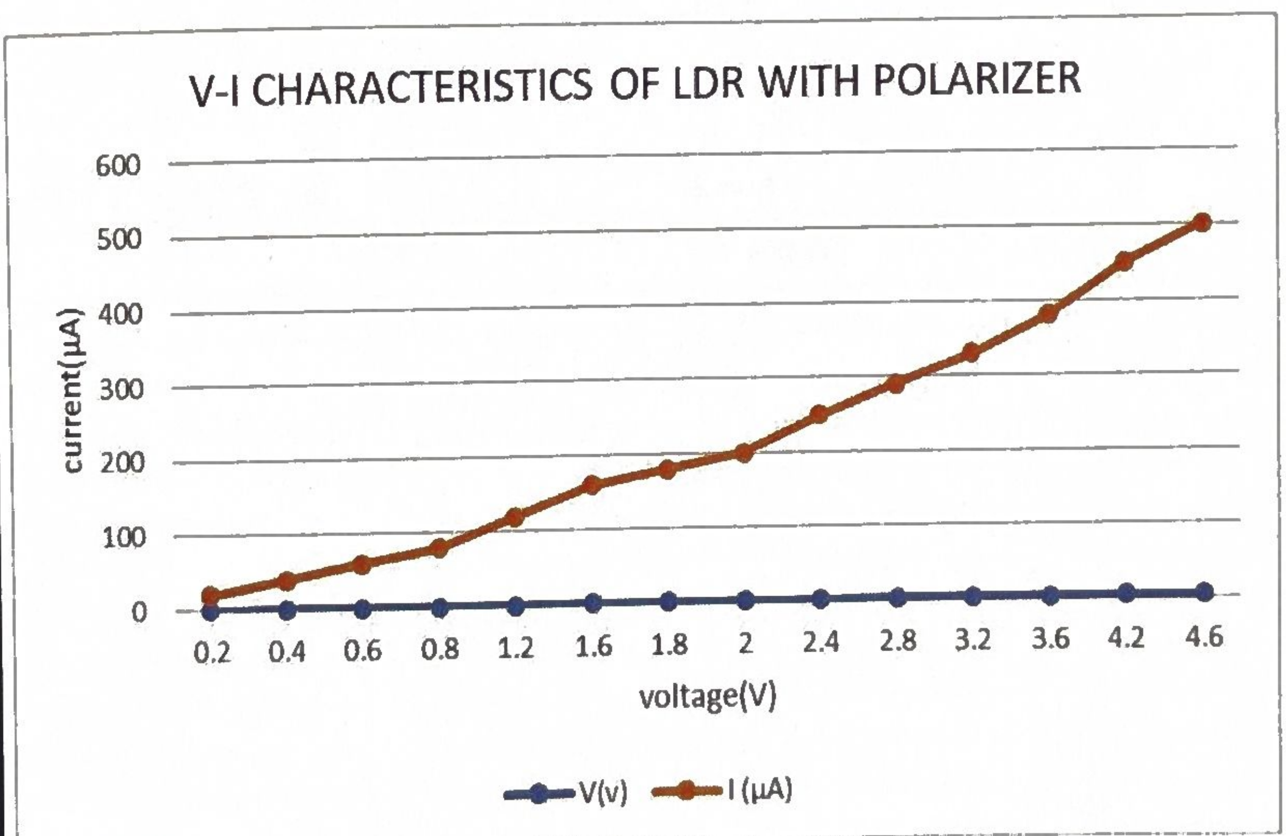
Without polarizer (using laser source)

V (v)	I (mA)	R(Ω)
0	10	0
0.2	20	0.01
0.4	40	0.01
0.6	60	0.01
0.8	80	0.01
1.2	120	0.01
1.6	160	0.01
1.8	180	0.01
2	200	0.01
2.4	250	0.0096
2.8	290	0.0096
3.2	330	0.0096
3.6	380	0.0094
4.2	450	0.0093
4.6	500	0.0092



With polarizer (using laser source)

V (v)	I (mA)	R(Ω)
0	10	0
0.05	30	0.01
0.1	60	0.0016
0.15	100	0.0015
0.2	140	0.0014
0.25	160	0.0015
0.3	200	0.0015
0.35	230	0.0015
0.4	280	0.0014
0.45	300	0.0015
0.5	360	0.0013
0.55	400	0.0013
0.6	440	0.0013
0.65	470	0.0013
0.7	500	0.0014

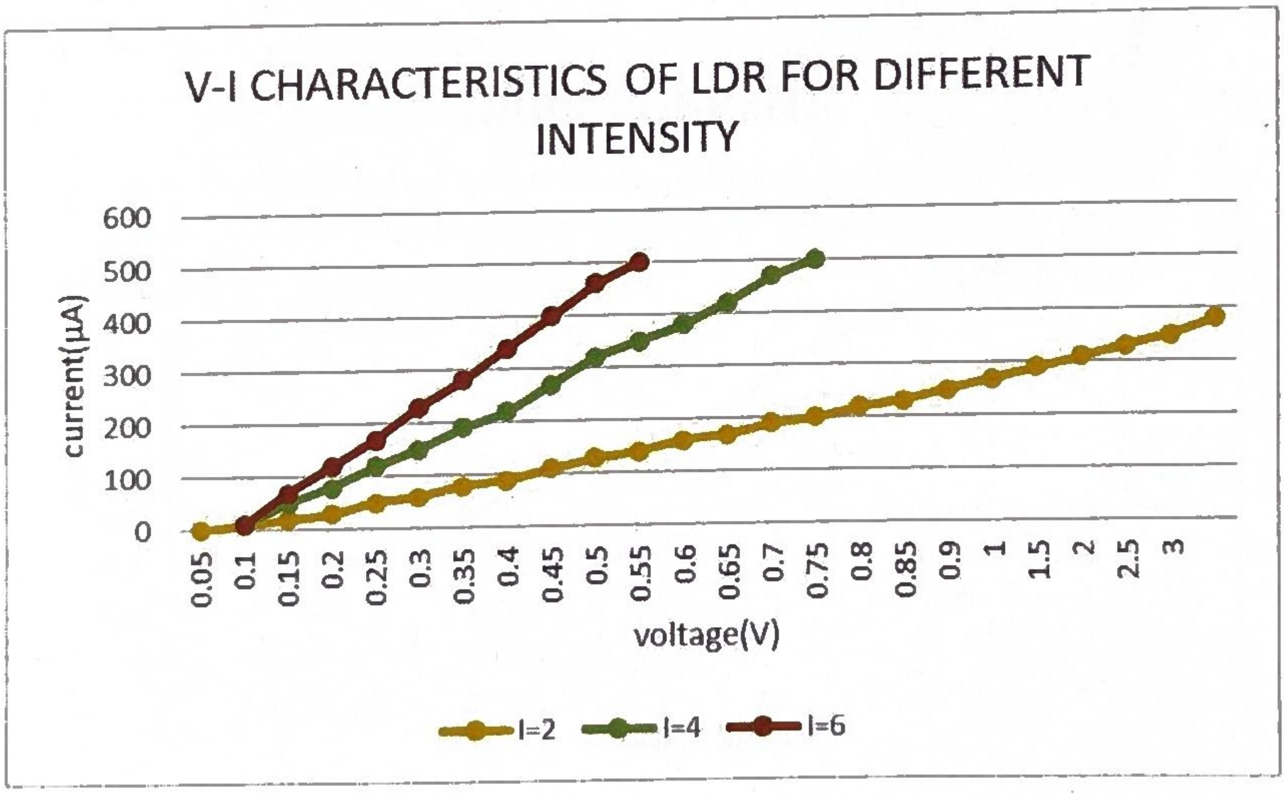


OBSERVATIONS (for different Intensities)

INTENSITY (I)	I = 2		
	V (v)	I (mA)	R(Ω)
1	0.05	10	0.005
2	0.1	20	0.005
3	0.2	50	0.004
4	0.25	60	0.004
5	0.3	80	0.003
6	0.45	130	0.003
7	5	140	0.035
8	0.65	190	0.003
9	0.7	200	0.003
10	0.85	250	0.003
11	0.9	270	0.003
12	1.5	310	0.004
13	2.5	350	0.007
14	3	380	0.007

INTENSITY (I)	I = 4		
	V (v)	I (mA)	R(Ω)
1	0.05	10	0.005
2	0.1	50	0.002
3	0.15	80	0.001
4	0.2	120	0.001
5	0.25	150	0.001
6	0.3	190	0.001
7	0.35	220	0.001
8	0.4	270	0.001
9	0.45	320	0.001
10	0.5	350	0.001
11	0.55	380	0.001
12	0.6	420	0.001
13	0.65	470	0.001
14	0.7	500	0.001

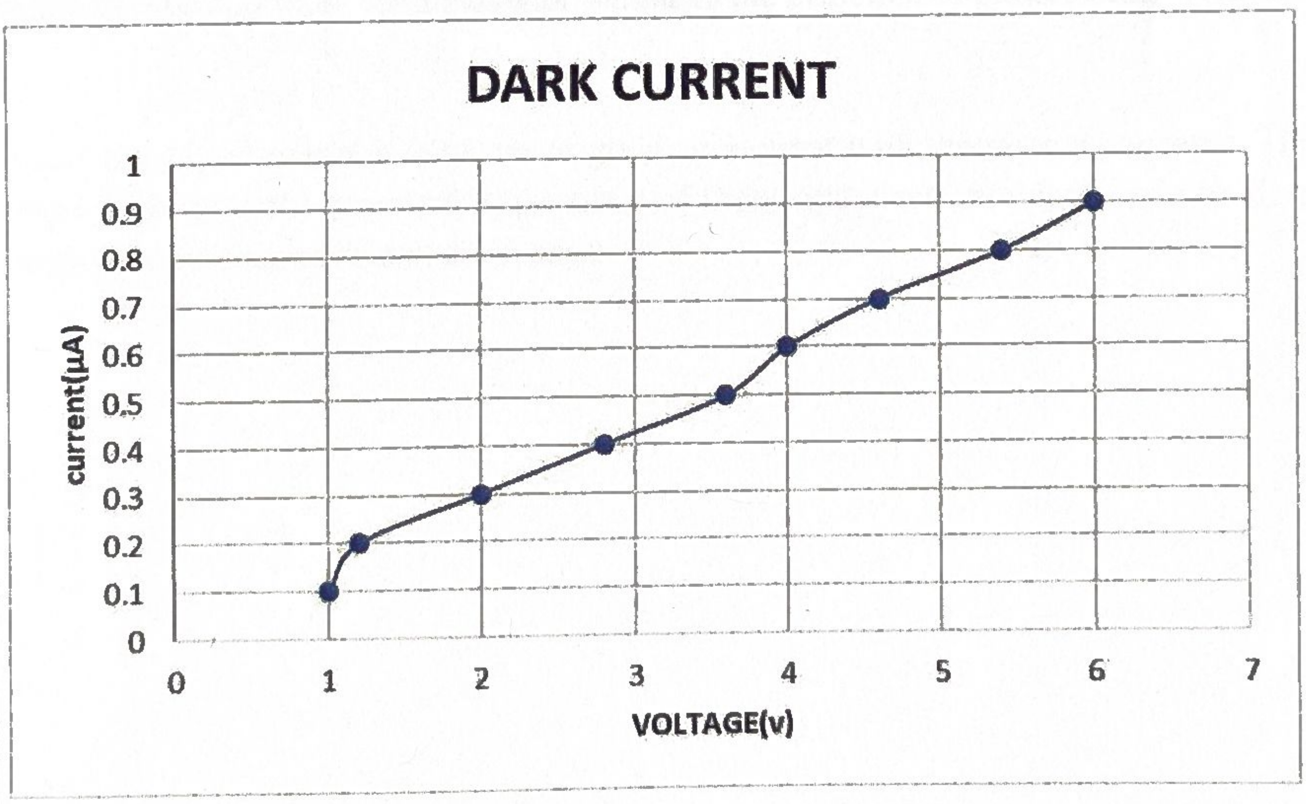
INTENSITY (I)	I = 6		
	V (v)	I (mA)	R(Ω)
1	0.05	10	0.005
2	0.1	70	0.001
3	0.15	120	0.001
4	0.2	170	0.001
5	0.25	230	0.001
6	0.3	280	0.001
7	0.35	340	0.001
8	0.4	400	0.001
9	0.45	460	0.0009
10	0.5	500	0.01



OBSERVATIONS

DARK CURRENT

V (v)	I (μA)	R (Ω)
	0.1	10
1.2	0.2	6
2	0.3	6.66
2.8	0.4	7
3.6	0.5	7.2
4	0.6	6.66
4.6	0.7	6.57
5.4	0.8	6.75
6	0.9	6.66



CONCLUSION

The project entitled "Characteristics of LED, Photodiode and LDR" was successfully carried out to study the electrical and optical behaviour of three important semiconductor devices.

From the experimental observations, it was found that the LED exhibits a non-linear V–I characteristic in forward bias, with a sharp increase in current after the threshold (cut-in) voltage. The emission of light due to electron–hole recombination confirms the principle of electroluminescence.

The photodiode was studied under both forward and reverse bias conditions. In reverse bias, the device showed a small dark current in the absence of light, and the reverse current increased significantly under illumination. This confirms that the photocurrent is directly proportional to the intensity of incident light and verifies the principle of photoelectric effect.

The LDR demonstrated a clear variation of resistance with change in light intensity. It was observed that the resistance is very high in darkness and decreases considerably when exposed to light. This behavior validates the principle of photoconductivity.

Thus, the experimental results are in good agreement with theoretical concepts. The study highlights the practical importance of these optoelectronic devices in modern electronic and communication systems.

List of References :-

Optoelectronics - John Wilson , john Hawkes, third edition, Pearson publication.